water

MDPI

Supplementary Material:

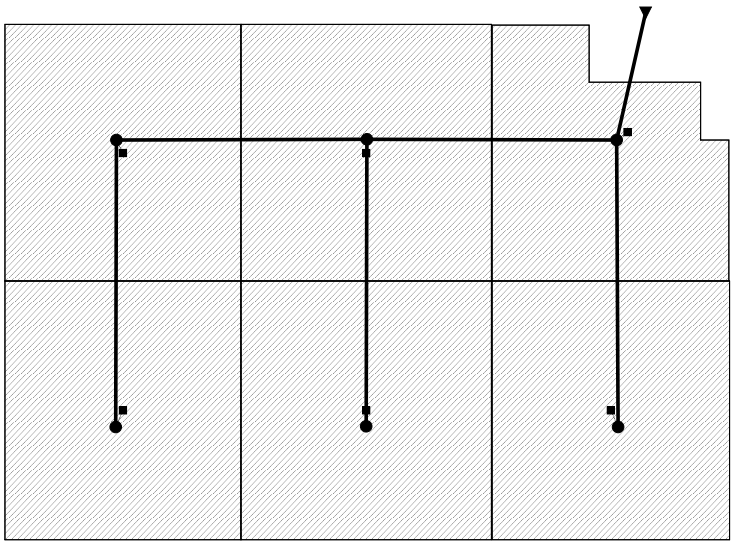
A) Additional study cases that reinforce the conclusions of the work.

One of the main challenges of meta-heuristic algorithms is that they are able to include all the features of real-world problems. However, the formulation problem of the complete system is complex, both because of the large number of decision variables that can be considered and because of the numerous constraints to satisfy. Obviously, as an increasing number of decision variables and choices, so does the size of the search space and find (near) global optimum solutions becomes exceptionally difficult. Offering a methodology to reduce the space of solutions is one of the contributions of this paper.

Obviously, a single case study may not be enough to prove the efficiency of the methodology. In this regard, most researchers demonstrate the goodness of their proposal on benchmarking networks widely studied in the literature, and finally apply their conclusions about a real case. However, the benchmarking networks available in the rehabilitation of drainage systems are scarce and not excessively complex. Consequently, it does not make sense to reduce the search space for a type of network that does not really need it.

As indicated in the main text (lines 164-167) the methodology with several networks has been validated. In order to be able to show the validity of the methodology in this document, the results of two networks are presented as supplementary material: a Basic network and the Ayurá network.

Case 1: Basic Network: 7 nodes and 6 conduits



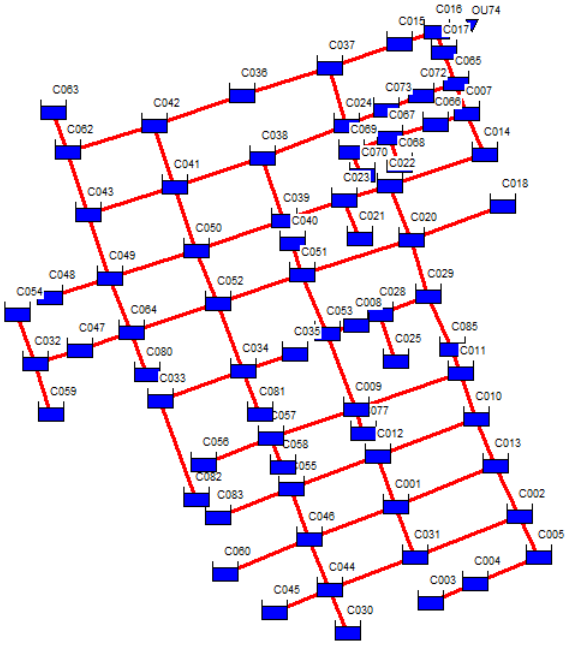
The application of the rehabilitation methodology generates 3 scenarios:

- Scenario 1: replacing ducts only
- Scenario 2: only installation of STs
- Scenario 3: installation of STs and rehabilitation of pipelines

The main results are those indicated in the following table. As the size of the network is low, it is not necessary to apply the SS reduction technique. However, it can be seen how the results are consistent with the conclusions of the paper.

Scenario	No. DVs		Objective Function	Terms in the objective function			No. elements in the solution	
	Nodes	Lines		Floods	STs	Pipes	STs	Pipes
1	0	6	446,854	15,982	0	430,872	0	6
2	6	0	263,601	3,719	259,881	0	6	0
3	6	6	247,239	6,484	184,651	56,104	4	3

Case 2: Ayurá Network: 73 nodes and 86 conduits



In this case, the size of the network suggests the convenience of applying the SS reduction described in main text. That is why 5 scenarios have been generated:

- Scenario 1: replacing ducts only
- Scenario 2: only installation of STs
- Scenario 3: installation of STs and rehabilitation of pipelines
- Scenario 4: reduction of the SS of scenario 3 considering a percentage of solutions of 10%.
- Scenario 5: reduction of the SS of scenario 3 considering a percentage of solutions of 5%.

The main results are those indicated in the following table. As in the previous case, the results are consistent with the conclusions presented. Moreover, the reduction of SS is again effective in improving the solutions.

Scenario	No. DVs		Objective Function	Terms in the objective function			No. elements in the solution	
	Nodes	Lines		Floods	STs	Pipes	STs	Pipes
1	0	86	392,599	11,278	0	381,321	0	56
2	73	0	518,916	46,934	471, 982	0	15	0
3	73	86	387,864	10,831	316,464	60,569	8	22
4	29	47	384,521	11,725	276,287	96,509	7	28
5	29	39	356,462	4,270	286,176	66,016	7	22

B) Data of the case study presented in the work.

The data can be pasted directly into a text file and saved as * .inp. This allows to have the complete network in epanet format.

```
[TITLE]
; Creado por SWMM 5.0.18 vE (GMMF - UPV)

[OPTIONS]
FLOW_UNITS              LPS
INFILTRATION            CURVE_NUMBER
FLOW_ROUTING            DYNWAVE
START_DATE              08/23/2013
START_TIME              00:00:00
REPORT_START_DATE       08/23/2013
REPORT_START_TIME       00:20:00
END_DATE                08/23/2013
END_TIME                03:00:00
SWEEP_START             01/01
SWEEP_END               12/31
DRY_DAYS                0
REPORT_STEP             0:00:30
WET_STEP                0:05:00
DRY_STEP                1:00:00
ROUTING_STEP            0:00:10
ALLOW_PONDING           NO
INERTIAL_DAMPING        PARTIAL
VARIABLE_STEP           0.00
LENGTHENING_STEP        0
MIN_SURFAREA            0
NORMAL_FLOW_LIMITED     BOTH
SKIP_STEADY_STATE       NO
FORCE_MAIN_EQUATION     D-W
LINK_OFFSETS            DEPTH
MIN_SLOPE               0

[EVAPORATION]
;;Tipo          Parámetros
;;---------- ----------
CONSTANT        0

[RAINGAGES]
;;                  Tipo de     Interv Factor Origen de
;;Nombre            Lluvia      Tiempo Nieve  Datos
;;--------------- --------- ------ ------ ----------
5                   INTENSITY 0:05   1      TIMESERIES 5
4                   INTENSITY 0:05   1      TIMESERIES 4

[SUBCATCHMENTS]
;;                                                    Área      Porcent.  Anchura   Pend.
Longitud Capa de
;;Nombre          Pluviómetro       Salida            Total     Imperm.   Width     Porcent.
Cuneta   Nieve
;;--------------- ---------------- ---------------- -------- -------- -------- -------- -------- --------
```

C01	5	N01	1.38	73.6	44	16.9	0
C02	5	N02	1.24	80.9	25	12.3	0
C03	5	N03	1.08	29.2	84	27.7	0
C04	5	N04	0.93	100	46	4.8	0
C05	5	N05	1.53	82.8	38	7	0
C06	5	N06	1.89	100	43	3.1	0
C07	5	N07	1.25	100	43	3.9	0
C08	5	N08	1.93	100	45	3.1	0
C09	5	N09	1.13	100	43	3.8	0
C10	5	N10	0.7	100	16	2	0
C11	5	N11	0.82	100	42	2.6	0
C12	5	N12	1.73	100	42	1.1	0
C13	5	N13	1	100	45	1.1	0
C14	5	N14	1.53	100	40	0.9	0
C15	5	N15	1.16	100	42	0.8	0
C16	5	N16	1.48	100	28	0.7	0
C17	5	N17	1	100	45	0.9	0
C18	5	N18	2.52	100	27	0.9	0
C19	5	N19	0.47	100	22	0.8	0
C20	5	N20	1.45	52.6	26	7.5	0
C21	5	N21	0.99	86.2	25	4.7	0
C22	5	N22	0.62	64.7	29	4.7	0
C23	5	N23	0.45	100	22	3.4	0
C24	5	N24	1.28	61.5	110	24.4	0
C25	5	N25	2.19	90.3	44	4.8	0
C26	5	N26	1.25	94.8	29	3.3	0
C27	5	N27	1.12	85.3	42	4.3	0
C28	5	N28	2.42	100	48	3.6	0
C29	5	N29	1.53	100	55	3.6	0
C30	5	N30	1.95	100	49	3.8	0
C31	5	N31	2.71	100	21	2.2	0
C32	5	N32	1.5	90.6	25	1.9	0
C33	5	N33	3.03	100	24	1.1	0
C34	5	N34	3.27	100	44	0.5	0
C35	5	N35	1.21	90.6	20	0.7	0

[SUBAREAS]

;;Subcuenca n Imperm. n Perm. S Imperm. S Perm. % Sin A/D Encauzam. % Encauzam.

;;---------- ---------- ---------- ---------- ---------- ---------- ---------- ----------

C01	0.01525	0.021	1.88	3.75	4.68	OUTLET
C02	0.01525	0.021	1.88	3.75	2.69	OUTLET
C03	0.01525	0.021	1.88	3.75	7.99	OUTLET
C04	0.01525	0.021	1.88	3.75	4.29	OUTLET
C05	0.01525	0.021	1.88	3.75	6.1	OUTLET
C06	0.01525	0.021	1.88	3.75	7.59	OUTLET
C07	0.01525	0.021	1.88	3.75	8.5	OUTLET
C08	0.01525	0.021	1.88	3.75	3.14	OUTLET
C09	0.01525	0.021	1.88	3.75	9.31	OUTLET
C10	0.01525	0.021	1.88	3.75	4.63	OUTLET
C11	0.01525	0.021	1.88	3.75	4.8	OUTLET
C12	0.01525	0.021	1.88	3.75	1.12	OUTLET
C13	0.01525	0.021	1.88	3.75	2.33	OUTLET

C14	0.01525	0.021	1.88	3.75	1	OUTLET
C15	0.01525	0.021	1.88	3.75	9.35	OUTLET
C16	0.01525	0.021	1.88	3.75	6.64	OUTLET
C17	0.01525	0.021	1.88	3.75	9.55	OUTLET
C18	0.01525	0.021	1.88	3.75	4.67	OUTLET
C19	0.01525	0.021	1.88	3.75	8.48	OUTLET
C20	0.01525	0.021	1.88	3.75	6.18	OUTLET
C21	0.01525	0.021	1.88	3.75	3.04	OUTLET
C22	0.01525	0.021	1.88	3.75	2.24	OUTLET
C23	0.01525	0.021	1.88	3.75	3.06	OUTLET
C24	0.01525	0.021	1.88	3.75	3.85	OUTLET
C25	0.01525	0.021	1.88	3.75	6.15	OUTLET
C26	0.01525	0.021	1.88	3.75	2.01	OUTLET
C27	0.01525	0.021	1.88	3.75	4.56	OUTLET
C28	0.01525	0.021	1.88	3.75	8.38	OUTLET
C29	0.01525	0.021	1.88	3.75	7.24	OUTLET
C30	0.01525	0.021	1.88	3.75	4.7	OUTLET
C31	0.01525	0.021	1.88	3.75	6.77	OUTLET
C32	0.01525	0.021	1.88	3.75	8.27	OUTLET
C33	0.01525	0.021	1.88	3.75	8.87	OUTLET
C34	0.01525	0.021	1.88	3.75	1.13	OUTLET
C35	0.01525	0.021	1.88	3.75	9.53	OUTLET

[INFILTRATION]

;;Subcuenca	Nº Curva	Cond. Hid.	Tiempo Sec
;;----------	----------	----------	----------
C01	80	10	7
C02	80	10	7
C03	80	10	7
C04	80	10	7
C05	80	10	7
C06	80	10	7
C07	80	10	7
C08	80	10	7
C09	80	10	7
C10	80	10	7
C11	80	10	7
C12	80	10	7
C13	80	10	7
C14	80	10	7
C15	80	10	7
C16	80	10	7
C17	80	10	7
C18	80	10	7
C19	80	10	7
C20	80	10	7
C21	80	10	7
C22	80	10	7
C23	80	10	7
C24	80	10	7
C25	80	10	7
C26	80	10	7
C27	80	10	7

C28	80	10	7
C29	80	10	7
C30	80	10	7
C31	80	10	7
C32	80	10	7
C33	80	10	7
C34	80	10	7
C35	80	10	7

[OUTFALLS]

;; Cota del Tipo de Nivel/Tabla
;;Nombre Fondo Vertido Serie Temporal Comp
;;-------------- ---------- ---------- ---------------- ----

V36	2548.36669	FREE		NO

[STORAGE]

;; Cota del Profund. Nivel Curva de Paramet. Área de Fracción
;;Nombre Fondo Máxima Inicial Almacenam. Curva Inundac. Evap. Infiltration Parameters
;;-------------- -------- -------- -------- ---------- -------- -------- -------- -------- -------- -----------------------

N01	2585.94	1.4	0	FUNCTIONAL	0	0	0	1380	0
N02	2574.53	2.25	0	FUNCTIONAL	0	0	0	1240	0
N03	2573.25	2.25	0	FUNCTIONAL	0	0	0	1080	0
N04	2567.97	1.72	0	FUNCTIONAL	0	0	0	930	0
N05	2575.26	2.06	0	FUNCTIONAL	0	0	0	1530	0
N06	2563.08	1.83	0	FUNCTIONAL	0	0	0	1890	0
N07	2563.67	2.45	0	FUNCTIONAL	0	0	0	1250	0
N08	2558.57	2.49	0	FUNCTIONAL	0	0	0	1930	0
N09	2560.66	1.32	0	FUNCTIONAL	0	0	0	1130	0
N10	2556.14	2.19	0	FUNCTIONAL	0	0	0	700	0
N11	2556.62	3.35	0	FUNCTIONAL	0	0	0	820	0
N12	2555.55	2.43	0	FUNCTIONAL	0	0	0	1730	0
N13	2555.97	2.74	0	FUNCTIONAL	0	0	0	1000	0
N14	2553.85	1.97	0	FUNCTIONAL	0	0	0	1530	0
N15	2555.04	1.38	0	FUNCTIONAL	0	0	0	1160	0
N16	2553.02	2.29	0	FUNCTIONAL	0	0	0	1480	0

N17	2553.31	2.1	0	FUNCTIONAL	0	0	0	1000	0
N18	2551.24	2.81	0	FUNCTIONAL	0	0	0	2520	0
N19	2552.88	1.38	0	FUNCTIONAL	0	0	0	470	0
N20	2575.59	1.25	0	FUNCTIONAL	0	0	0	1450	0
N21	2570.06	1.57	0	FUNCTIONAL	0	0	0	990	0
N22	2572.07	1.9	0	FUNCTIONAL	0	0	0	620	0
N23	2564.59	2.61	0	FUNCTIONAL	0	0	0	450	0
N24	2587.65	2.6	0	FUNCTIONAL	0	0	0	1280	0
N25	2568.14	2.26	0	FUNCTIONAL	0	0	0	2190	0
N26	2571.98	1.48	0	FUNCTIONAL	0	0	0	1250	0
N27	2571.38	2.42	0	FUNCTIONAL	0	0	0	1120	0
N28	2561.86	2.63	0	FUNCTIONAL	0	0	0	2420	0
N29	2569.21	1.53	0	FUNCTIONAL	0	0	0	1530	0
N30	2565.41	1.28	0	FUNCTIONAL	0	0	0	1950	0
N31	2556.5	3.49	0	FUNCTIONAL	0	0	0	2710	0
N32	2559	0.91	0	FUNCTIONAL	0	0	0	1500	0
N33	2553.39	1.94	0	FUNCTIONAL	0	0	0	3030	0
N34	2548.97	3.07	0	FUNCTIONAL	0	0	0	3270	0
N35	2548.43	3.07	0	FUNCTIONAL	0	0	0	1210	0

[CONDUITS]

;;	Nudo	Nudo		Coef. n	Desnivel	Desnivel	Caudal	Caudal
;;Nombre	Entrada	Salida	Longitud	Manning	Entrada	Salida	Inicial	Máximo
;;--------------	----------------	----------------	----------	----------	----------	----------	----------	----------
P01	N01	N02	172.65	0.011	0	0	0	0
P02	N02	N03	90.99	0.011	0	0	0	0
P03	N03	N04	93.17	0.011	0	0	0	0

P04	N04	N06	187.94	0.011	0	0	0
P05	N05	N04	180.27	0.011	0	0	0
P06	N06	N08	203.82	0.011	0	0	0
P07	N07	N06	85.55	0.011	0	0	0
P08	N08	N10	113.02	0.011	0	0	0
P09	N09	N08	85.62	0.011	0	0	0
P10	N10	N12	81.8	0.011	0	0	0
P11	N11	N10	68.24	0.011	0	0	0
P12	N12	N14	187.31	0.011	0	0	0
P13	N13	N12	80.08	0.011	0	0	0
P14	N14	N16	169.06	0.011	0	0	0
P15	N15	N14	79.98	0.011	0	0	0
P16	N16	N18	270.92	0.011	0	0	0
P17	N17	N16	84.81	0.011	0	0	0
P18	N18	N34	90.38	0.011	0	0	0
P19	N19	N18	66.74	0.011	0	0	0
P20	N20	N21	124.22	0.011	0	0	0
P21	N21	N23	79.16	0.011	0	0	0
P22	N22	N21	52.91	0.011	0	0	0
P23	N23	N28	194.54	0.011	0	0	0
P24	N24	N25	270.94	0.011	0	0	0
P25	N25	N23	85.78	0.011	0	0	0
P26	N26	N27	91.21	0.011	0	0	0
P27	N27	N25	203.14	0.011	0	0	0
P28	N28	N31	201.07	0.011	0	0	0
P29	N29	N30	180.09	0.011	0	0	0

P30	N30	N28	197.82	0.011	0	0	0
0							
P31	N31	N33	187.12	0.011	0	0	0
0							
P32	N32	N31	88.46	0.011	0	0	0
0							
P33	N33	N18	273.72	0.011	0	0	0
0							
P34	N34	N35	337.56	0.011	0	0	0
0							
P35	N35	V36	33.19	0.011	0	0	0
0							

[XSECTIONS]

;;Línea	Forma	Geom1	Geom2	Geom3	Geom4	Vanos
;;----------	----------	----------	----------	----------	----------	----------
P01	CIRCULAR	0.4	0	0	0	1
P02	CIRCULAR	0.4	0	0	0	1
P03	CIRCULAR	0.4	0	0	0	1
P04	CIRCULAR	0.55	0	0	0	1
P05	CIRCULAR	0.4	0	0	0	1
P06	CIRCULAR	0.6	0	0	0	1
P07	CIRCULAR	0.4	0	0	0	1
P08	CIRCULAR	0.75	0	0	0	1
P09	CIRCULAR	0.4	0	0	0	1
P10	CIRCULAR	0.75	0	0	0	1
P11	CIRCULAR	0.3	0	0	0	1
P12	CIRCULAR	0.9	0	0	0	1
P13	CIRCULAR	0.4	0	0	0	1
P14	CIRCULAR	1.1	0	0	0	1
P15	CIRCULAR	0.5	0	0	0	1
P16	CIRCULAR	1.2	0	0	0	1
P17	CIRCULAR	0.4	0	0	0	1
P18	CIRCULAR	1.3	0	0	0	1
P19	CIRCULAR	0.4	0	0	0	1
P20	CIRCULAR	0.45	0	0	0	1
P21	CIRCULAR	0.45	0	0	0	1
P22	CIRCULAR	0.3	0	0	0	1
P23	CIRCULAR	0.6	0	0	0	1
P24	CIRCULAR	0.56	0	0	0	1
P25	CIRCULAR	0.6	0	0	0	1
P26	CIRCULAR	0.4	0	0	0	1
P27	CIRCULAR	0.55	0	0	0	1
P28	CIRCULAR	0.75	0	0	0	1
P29	CIRCULAR	0.5	0	0	0	1
P30	CIRCULAR	0.6	0	0	0	1
P31	CIRCULAR	0.85	0	0	0	1
P32	CIRCULAR	0.4	0	0	0	1
P33	CIRCULAR	1	0	0	0	1
P34	CIRCULAR	1.4	0	0	0	1
P35	CIRCULAR	1.4	0	0	0	1

```
[LOSSES]
;;Línea            Entrada    Salida     Media      Compuerta
;;-------------- ---------- ---------- ---------- ----------

[TIMESERIES]
;;Nombre           Fecha      Hora       Valor
;;-------------- ---------- ---------- ----------
5                             0:00       11.54
5                             0:05       16.83
5                             0:10       26.74
5                             0:15       48.7
5                             0:20       81.38
5                             0:25       81.38
5                             0:30       39.64
5                             0:35       26.98
5                             0:40       19.52
5                             0:45       14.75
5                             0:50       11.54
5                             0:55       8.87

4                             0:00       16.56
4                             0:05       24.23
4                             0:10       38.6
4                             0:15       70.44
4                             0:20       117.75
4                             0:25       117.75
4                             0:30       57.3
4                             0:35       38.94
4                             0:40       28.12
4                             0:45       21.22
4                             0:50       16.56

[REPORT]
INPUT        NO
CONTROLS     NO
SUBCATCHMENTS ALL
NODES ALL
LINKS ALL

[TAGS]

[MAP]
DIMENSIONS 1335503.176 1009133.376 1337159.424 1010178.464
Units        Ninguno

[COORDINATES]
;;Nudo             Coordenada X       Coordenada Y
;;-------------- ------------------ ------------------
V36                1335578.460        1010129.910
N01                1336969.520        1009338.540
N02                1337043.370        1009488.840
N03                1337084.140        1009570.190
N04                1337001.430        1009613.090
```

N05	1336919.970	1009452.300
N06	1336834.650	1009699.720
N07	1336795.410	1009623.700
N08	1336653.920	1009793.950
N09	1336614.400	1009718.000
N10	1336553.640	1009846.070
N11	1336531.760	1009786.680
N12	1336480.880	1009883.460
N13	1336443.970	1009812.390
N14	1336314.670	1009969.820
N15	1336277.690	1009898.900
N16	1336175.241	1010044.454
N17	1336125.350	1009972.540
N18	1336000.848	1009935.275
N19	1335969.250	1009872.800
N20	1336850.910	1009408.120
N21	1336821.630	1009498.260
N22	1336798.000	1009450.920
N23	1336751.300	1009539.290
N24	1336856.190	1009226.110
N25	1336711.680	1009463.210
N26	1336617.590	1009210.880
N27	1336618.040	1009282.940
N28	1336578.730	1009629.100
N29	1336532.980	1009334.410
N30	1336487.290	1009453.680
N31	1336400.830	1009722.850
N32	1336357.770	1009646.930
N33	1336234.210	1009807.980
N34	1335910.570	1009974.780
N35	1335611.630	1010130.960

[VERTICES]

;;Línea	Coordenada X	Coordenada Y
;;----------	----------	----------
P01	1337000.440	1009370.580
P01	1336995.740	1009402.890
P01	1337018.460	1009444.020
P11	1336558.380	1009840.090
P16	1336093.870	1010082.640
P16	1336079.480	1010081.040
P16	1336045.650	1010012.490
P16	1336005.660	1009936.620
P19	1335994.690	1009917.650
P20	1336850.660	1009412.690
P20	1336873.430	1009457.250
P20	1336867.250	1009474.490
P21	1336759.810	1009527.970
P21	1336754.120	1009537.960
P24	1336837.940	1009242.420
P24	1336726.540	1009455.090
P26	1336592.610	1009229.600
P28	1336467.510	1009685.460

P29	1336571.560	1009407.330
P29	1336568.730	1009413.400
P31	1336324.080	1009762.680
P32	1336388.850	1009705.310
P32	1336393.720	1009709.470
P33	1336115.580	1009871.130
P34	1335770.010	1010049.670
P34	1335740.780	1010063.160
P34	1335679.740	1010090.470

[Polygons]

; Subcuenca	Coordenada X	Coordenada Y
;----------	----------	----------
C01	1336939.520	1009308.540
C02	1337013.370	1009458.840
C03	1337054.140	1009540.190
C04	1336971.430	1009583.090
C05	1336889.970	1009422.300
C06	1336804.650	1009669.720
C07	1336765.410	1009593.700
C08	1336623.920	1009763.950
C09	1336584.400	1009688.000
C10	1336523.640	1009816.070
C11	1336501.760	1009756.680
C12	1336450.880	1009853.460
C13	1336413.970	1009782.390
C14	1336284.670	1009939.820
C15	1336247.690	1009868.900
C16	1336134.620	1010017.710
C17	1336095.350	1009942.540
C18	1335960.840	1009903.240
C19	1335939.250	1009842.800
C20	1336820.910	1009378.120
C21	1336791.630	1009468.260
C22	1336768.000	1009420.920
C23	1336721.300	1009509.290
C24	1336826.190	1009196.110
C25	1336681.680	1009433.210
C26	1336587.590	1009180.880
C27	1336588.040	1009252.940
C28	1336548.730	1009599.100
C29	1336502.980	1009304.410
C30	1336457.290	1009423.680
C31	1336370.830	1009692.850
C32	1336327.770	1009616.930
C33	1336204.210	1009777.980
C34	1335880.570	1009944.780
C35	1335581.630	1010100.960

```
[SYMBOLS]
; Pluviómetro      Coordenada X          Coordenada Y
;---------------- ------------------- -------------------
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